Biological control of taro scarab beetle (Papuanauninodis Coleoptera: Scarabaeidae) instars via Scoliid and Voria Tachinidae parasitoid wasps

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Research article

BIOLOGICAL CONTROL OF TARO SCARAB BEETLE *(PAPUANAUNINODIS, COLEOPTERA: SCARABAEIDAE)* INSTARS VIA *SCOLIID AND VORIA TACHINIDAE* PARASITOID WASPS

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ABSTRACT: *Scoliid* and *Voria Tachinidae* parasitoid wasps are shown to be able to control the population of the Taro Scarab beetle *(Papuanauninodis, Coleoptera: Scarabaeidae)* larvae using a newly created continuous-time simulation model based on non-linear ordinary differential equations that track the populations of the beetle's life cycle stages: egg, larva, pupa, adult and the populations of the two parasitoid wasps. Due to the fact that the scarab beetles are, relatively speaking, long lived it is challenging to drive down the adult population below the environmental carrying capacity. Mortality and predator/prey capture rates are modelled using the Weibull and Pascal probability distribution functions, respectively. We suggest the use of a virus or fungi to drive down the population of the adult beetles, the ambition being to avoid the use of pesticides so as to produce higher quality food that doesn't damage human health via chemical residues.

Keywords: Biological control, Scarab Beetles, Parasitoid wasps, pesticides, Taro, Yam, Modelling

INTRODUCTION

Scarab beetles are a species from the family scarabaeidae, which are widely distributed across the globe, (Ratcliffe, 2002) and (Powell, 2009). The larvae are called grubs, they do not like sunlight, therefore they live under debris or underground. Many of the scarab beetle species are scavengers that recycle decaying plant material, while others are devastating agricultural pests. Some of the well-known beetles from the Scarabaeidae family, which are pests are: Japanese beetles, Dung beetles, June beetles, Rose chafers (Australian, European and North American), Rhinoceros beetles, Hercules beetles, Goliath beetles, Sweet potato beetles, Cocoyam or Taro *(Colocasiaesculenta)* beetles *(Papuanauninodis, Coleoptera: Scarabaeidae)*, (Bedford, 1980), (Smee, 1965),and (Jarvis, 1932). For the purposes of this research work we shall concentrate our investigation on the Cocoyam or Taro *(Colocasiaesculenta)* corm beetles called Elephant ear beetles. This is because of the economic importance of root crops across many nations; apart from home consumption and cash crop sales on local markets and export earnings, cocoyam has important cultural attributes: it plays a part in traditional exchanges and social obligations – marriage ceremonies, religious commitments and reconciliations. It is a tropical starchy root crop, which is a staple food in many subsistence communities, particularly in Nigeria and across many nations including the Pacific islands, (Iwuoha & Kalu, 1995). Cocoyam with its high dietary fiber content is very rich in vitamin B6 and magnesium, which helps control high blood pressure and protect the heart and is good for glucose metabolism. For most of the Nigerian communities, cocoyam is an essential part of their diet, it makes up almost 20% of daily calorific food intake and it is easily digestible, (Fitday, 2014).

This root crop often comes under severe attack by major insect pests like scarab beetles, aphids, armyworm, hawk moth and plant hopper - leaving serious damage to the leaf, various parts of the plant and roots, which causes a lot of disfiguration to the root crop as shown in Fig.1. Careful studies on the degree of damage revealed that of all the different pests that attack the root crops, the scarab beetle is the major threat. In order to combat the threat, researchers over the years formulated different strategies, which include: the use of persistent and toxic organochlorine insecticides such as 6% Lindane (Gamma BHC) for chemical control, (Jackson et al, 1992), which can no longer be used because of concerns over residues and toxicity, (Potter & held, 2002). (Zimmerman, 1992) and (Rath, 1992) proposed the use of a Pathogen.

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(Bedford, 1986), (Waterhouse & Norris, 1987) and (Young, 1986) proposed *Oryctes rhinoceros* virus and introduced it as a biocontrol agent. (Glare, 1992) and (Shaw, 1984) demonstrated the use of fungi *Metarhiziumanisopliae* and *Beauveria* spp on the scarab grubs. (Theunis & Aloali, 1999) introduced the bacteria *Bacillus thuringiensis* and *Paenibacillus* as a biocontrolagent for the scarab grubs and (Klein, 1990), applied Nematodes (steinernematids and heterorhabditids), (Morris & Grewal, 2011) confirmed the susceptibility of beetles to nematodes, and (Faithpraise et al, 2013c), proposed a detection and recognition system to detect and recognize plant pests in their various forms and orientations. Biological control by the use of natural beneficial insects was reported as a failed approach and was ineffective as illustrated by (Smith, 1985), (Wilson, 1960), (Fabricius, 1793), (Lepeletier, 1845), and (Lopez, 1933).

MATERIALS AND METHODS

To prove the value of naturally beneficial insects, we decided to investigate the control of cocoyam or taro beetles, and look at the effect of deploying two larval parasitoid *Scoliidae* and *Tachinidae* wasps. Experimental studies on the biology of the Scarab beetles (Taro or Cocoyam beetles) indicate that adult females live up to 22 months and lay up to 300 hundred eggs during its lifespan of which 75% of the eggs are laid within the first 3 months. Table 1 gives an account of the detailed lifecycle of the Scarab beetles. To curtail the activities of the scarab beetles, it is advisable to be familiar with the biology as illustrated in the life cycle of Table 1 and Fig.2.

Table-1: The mean gestation time and average lifespan of the Cocoyam or Taro beetles as demonstrated by (Roy, 2014), (Autar et al., 1988) and (Sada, 2014)

Beetles life cycle	Length of Incubation period
Eggs	14 - 18 days
Larvae (1st and 2nd instar)	18 days
Larvae (3rd instar)	55 days
Pre-pupae	7 days
pupae	30 days
Adults	22 months or 660 days

Scarab beetles strategies of operation

The adults root crop beetles (Taro, sweet potato, yams, and potato) burrow into corms of *(Colocasiaescu/enta)* and other aroids *(Xanthosomasagittifolium, Cyrtospennachamissonis)* making smooth sided tunnels with the same diameter as their width. In severely damaged plants, the tunnels run to form large cavities through which secondary rot frequently develops. The beetles sporadically may also ring bark young tea, cocoa, and coffee plants in the field and bore into seedlings of oil palm and cocoa, (Theunis & Aloali, 1993), (Solulu & Darie, 1990), and (Thistleton, 1984) as displayed in Fig. 1.

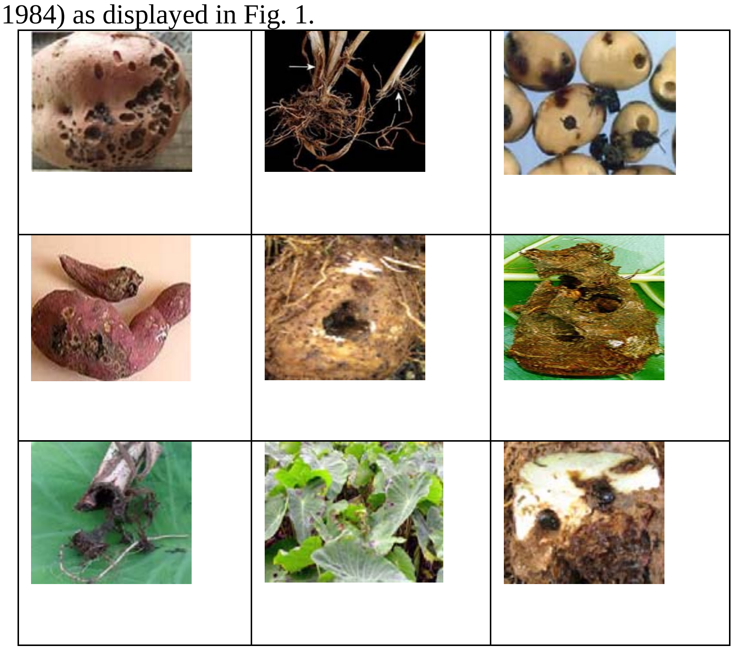

Figure 1. The destruction of root crops by scarab beetles

Looking at the images in Fig. 1, it is sad to behold the disfiguration and damage caused by the *Colocasiaescu/enta* beetles, which threaten food security and cause hard ship or starvation for the local population. To restore confidence to crop growers and provide food security to communities that are discouraged and have abandoned the cultivation of these root crops; an effective control system is developed based on modelling of the beetle's interaction with parasitoid wasps, previously illustrated by (Faithpraise et al, 2014a), on the control of Armyworm outbreak. The Effective Control Model (EFM) is based on the introduction of parasitoid wasps. *Scoliids* and *Tachinidae*, which are both naturally beneficial parasitoid wasps which parasitizes the 2nd or 3rd instar stages of *Scarabaeid* larvae, (Illingworth & Jarvis, 1920). For a discussion on methods of automated deployment of naturally beneficial insects, see (Faithpraise et al., 2013b). The EFM concept provides a general opportunity for the control of all classes and species of *Scarabaeid* larvae, as it is based on the interaction between the population of all species of adult Scarab beetles and its life cycle stages (egg, larvae and pupae) and the naturally beneficial insects: *Scoliid* and *Tachinidae* parasitoid wasps. Fig. 2, illustrates the life cycle of a scarab beetles. The blue arrows indicate the normal state flow of the life cycle of a scarab beetles, it demonstrates how the adult beetles lay their eggs, after a time, the eggs transform to larvae, which pupate and the turn into adult beetles. Once the *Scoliid*or *Tachninid* wasps lay their eggs in the beetle larvae as indicated by the large pink arrow, the reproductive life cycle of the beetles is disrupted as the beetle larvae produce *scoliid* wasps or *tachinid* wasps rather than turning into pupae and then into beetles. This is indicated by the green boxes in Fig. 2.

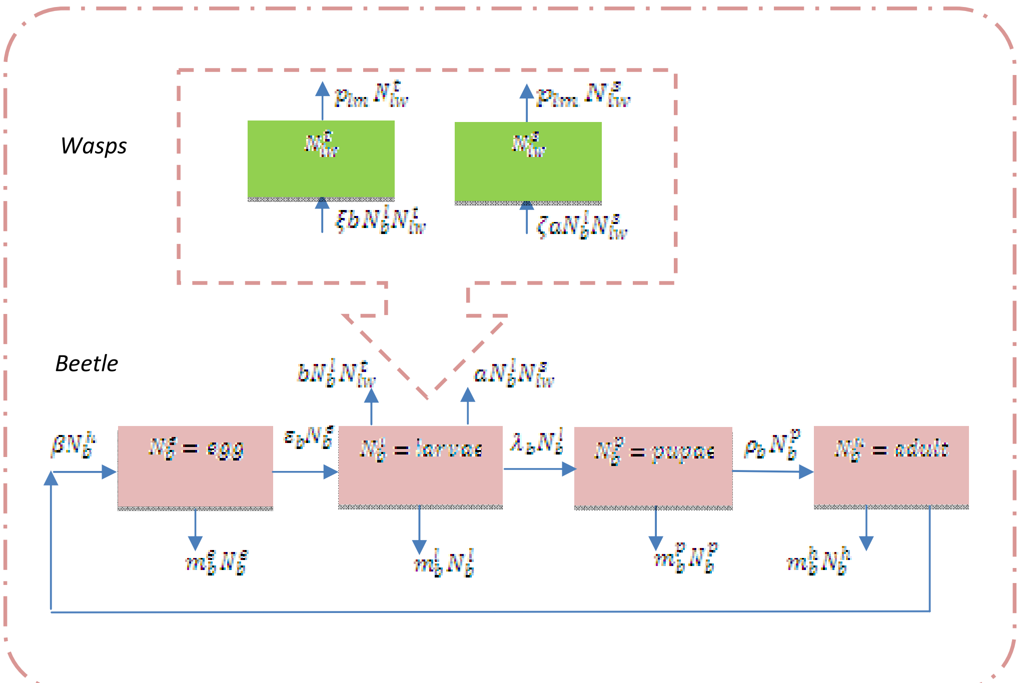

Figure (2) Population dynamics schematic for wasp-beetle interaction model describing the detailed activities of how the wasps exercise control over the beetle population in its habitat, see equations 1 to 6.

Mode of Operation of the Parasitoid wasps

Scoliidae wasps as illustrated by (Bhattacharjee & Raychaudhuri, 2010) are known as ground wasps, as they work their way through the soil, digging burrows in order to locate their prey, sting them (beetle larvae) and lay an egg on the paralysed insect, they cover the burrow on their way out, (Elliott, 2011). It has the ability to sting many grubs that never recover from the paralysis, it then lays a single mature egg on a few hosts,which hatch in about three days to continue their life cycle, Barbara, 2003. After hatching, the *scoliidae* larva feeds on its host for approximately one to two weeks and then spins an underground cocoon, (Krombein, 1963) from which the adult wasp emerges in an average of about five weeks, the *scoliidae* wasp lays eggs continuously for two months and has a life span of 4 -5 months, (Misra, 1996), (Grissell, 2007) and (David et al., 1999). The *Tachinidae* larvae parasitoid wasps employs different strategies of oviposition to attack its host, (Imms, 1977) noted *Gonia, Sturmia* and *Zenillia* as species, which lays many thousands of matured "micro-eggs" on foliage near the host insect, and the eggs are ingested during feeding by the host after which they hatch immediately into larvae.

(Imms, 1977) also noted *Winthemia*, *Eutachina*, *Thrixion*, and *Gymnosoma* species as those that glue eggs to the body of the host, the larva penetrate into the host's body after the egg hatches. (Wood, 1987) identified *Plagia*, *Exorista* and *Voria* female species as possessing a piercing ovipositor, which is used to insert their eggs into the host's body. In all cases, *tachinid* larvae feed internally in their hosts, after killing its host; the larvae exit the host's body to pupate, (Stireman et al., 2006). The pupae are commonly oblong and dark, (Hoell et al., 1998). The larval wasps development is usually completed in one to three weeks, as the lifecycle lasts for three to four weeks, only one larva survives within each pest (host), (Chaudhari, 2013), (Pickett et al., 1996) and (O'Hara et al. 2008). After considering the biology and the life cycle stages of the pest, scarab beetles and the parasitoid wasps; a model of their interacting populations was designed to observe the effect of these combined wasps (*Scoliids* and *Tachinidae*) on the scarab beetle population, as illustrated by the following non-linear simultaneous ordinary differential equations. The equations can be interpreted by looking at Fig. 2, which illustrates the flow of population. Equations 1 to 6, provide a dynamic model of the evolving scarab beetle (Taro or Cocoyam corm) life cycle stages, the *scoliid* wasps and the *Voria* species of the *tachinidae* wasps per square metre. The model simulates reproduction, mortality and parasitism.

$$\frac{dN_b^e}{dt} = \beta_b N_b^h - \varepsilon_b N_b^e - m_b^e N_b^e \qquad \text{Eqn. 1}$$

$$\frac{dN_b^l}{dt} = \varepsilon_b N_b^e - \lambda_b N_b^l - aN_b^l N_{lw}^s - bN_b^l N_{lw}^t - m_b^l N_b^l \qquad \text{Eqn. 2}$$

$$\frac{dN_{lw}^s}{dt} = \zeta a\ N_b^l N_{lw}^s - p_{lm} N_{lw}^s \qquad \text{Eqn. 3}$$

$$\frac{dN_{lw}^t}{dt} = \xi b N_b^l N_{lw}^t - p_{lm} N_{lw}^t \qquad \text{Eqn. 4}$$

$$\frac{dN_b^p}{dt} = \lambda_b N_b^l - \rho_b N_b^p - m_b^p N_b^p \qquad \text{Eqn. 5}$$

$$\frac{dN_b^h}{dt} = \{\rho_b N_b^p - m_b^h N_b^h\}\left[N_b^h \left(\frac{K_b^h - N_b^h}{K_b^h}\right)\right] \qquad \text{Eqn. 6}$$

where:

$N_b^h, N_b^e, N_b^l, N_b^p$ = Population density of Cocoyam beetles: adult, egg, larvae and pupae.

N_{lw}^s, N_{lw}^t = Population density of *Scoliid* and *Tachinidae* wasp.

K_b^h = Population carrying capacity of the environment for adult: Taro beetle.

$m_b^h, m_b^e, m_b^l, m_b^p$ = Cocoyam beetles mortality rate: adult, egg, larvae and pupae respectively.

p_{lm}, p_{lm} = *Scoliid* and *Tachinidae* wasp mortality rate respectively.

ξ = efficiency of turning the pest larva into *Tachinidae* wasps

ζ = efficiency of turning the pest larva into *Scoliid* parasitoid wasps

a, b = probability that a parasitoid wasps finds and parasitizes a larva prey

β_b = Number of eggs laid per day bythe Taro beetle

ε_b = Fraction of eggs hatching into beetle larvae

λ_b = Fraction of beetles larvae changing to pupae

ρ_b = Fraction of pupae turning into adult Taro beetle

The proposed model consists of six simultaneous non-linear, ordinary differential equations (1) to (6), which are solved using a 4th order Runge–Kutta method as described by (Klassische, 1969), (Dormand and Prince, 1981), (Butcher, 2007) and (Schreiber, 2007) and using the average life span of all the insect life cycle stages and their mortality rates as described in the previous works of (Faithpraise et al., 2013a). The following results were obtained from the combination of the average life span of all the insects described above. The Weibull probability distribution function was used to determine the various mortality rates of the pests and predators; for the detailed procedure refer to (Faithpraise et al., 2014c, 2014d). To determine the probability with which the parasitoid wasps locate and parasitize the host, we used a negative binomial distribution, where the negative binomial probability distribution function (pdf) is evaluated using equation 7, and the negative binomial cumulative distribution function (cdf) is evaluated from equation 8.

$$y = f(x|r,p) = \binom{r+x-1}{x} p^r (1-p)^x I_{(0,1,2,\dots)}(x) \quad \text{Eqn. 7}$$

$$y = F(x|r,p) = \sum_{i=0}^{x} \binom{r+i-1}{i} p^r (1-p)^i I_{(0,1,2,\dots)}(i) \quad \text{Eqn. 8}$$

Where:

Equation 7 and equation 8 returns the negative binomial pdf and cdf at each of the values of 'x' using the corresponding number of successes, 'r' and probability of success in a single trial, 'p'. Where X is the number of trials needed to achieve a particular success rate 'r'

This models the scenario for the successive random trials that the parasitoid wasps undertake, with each attempt having a probability of success 'p'. The number of attempts that the wasps must perform in order to locate and parasitize a given number of hosts 'r' has a negative binomial distribution where 'I' is the indicator function, which ensures that 'r' only adopts integer values. For more detailed analysis refer to (Faithpraise et al., 2014b). The model of interaction between the Scarab beetles and the parasitoid wasps considered an established infestation of Cocoyam or Taro beetles with numerous populations of the adult, eggs, larvae and pupae. For this simulation model 5 Cocoyam adult beetles were used with an initial population of 60 eggs, 40 larvae and 20 pupae per square metre of cocoyam cultivated field, the population density of the beetles increases as illustrated in Fig. 3, with great damage to the cocoyam field. The environmental carrying capacity was set to 25 beetles per square metre. To control the damage to the field 6 *Scoliidae* and 6 *Tachinidae* wasps were introduced into the infested habitat. Fig 4 illustrates in the result after a 90 day period.

RESULTS AND DISCUSSION

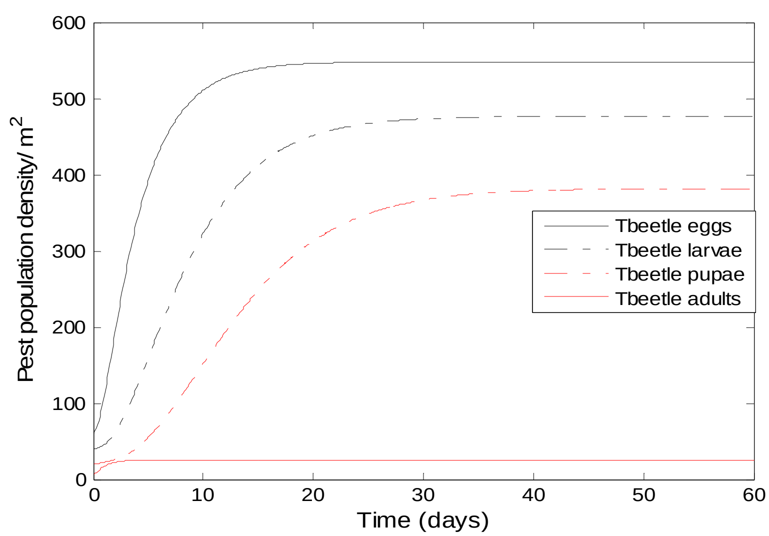

Figure 3. Rate of increase of Scarab beetles in the absence of any control measures

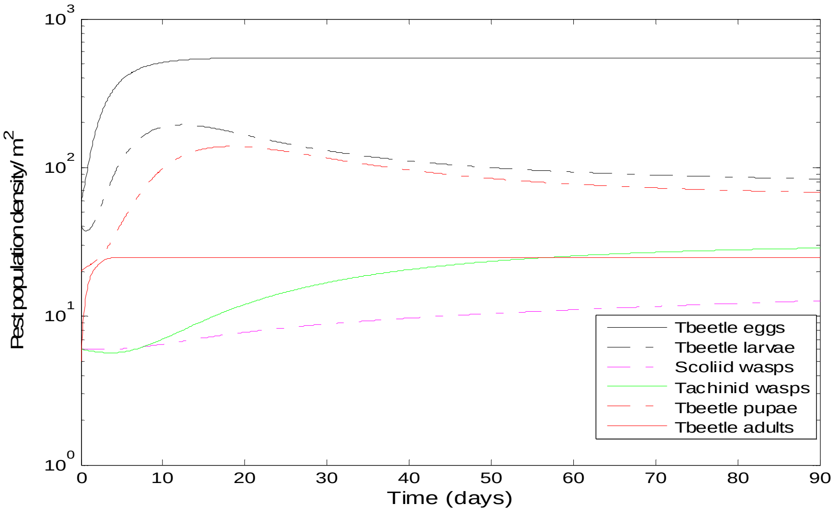

Figure 4. The effect of beneficial insects on the control of scarab beetles – semi-log plot

The result of Fig. 3 shows that it is possible to have Scarab beetle outbreaks when an ecosystem is left unattended, as observed by the reproduction rate of the Scarab beetles on the cocoyam corm field within an interval of 60 days. The population increased from an initial starting population of 60, 40, 20 and 5 for the egg, larvae, pupae and adults to a peak of 549 eggs, 477 larvae and 382 pupae and the adult population reached the environmental carrying capacity, rising from the initial 5 to 25 adults beetles in six days. The result of Fig. 4 shows a measure of control is exhibited when the *scoliidae* and *tachinidae* wasps which were introduced into the habitat, the population of the beetles larvae and pupae where under firm control. There was an increase from the initial population densities of 40 and 20 for the larvae and pupaeto peaks at 195 larvae and 139 pupae during the first 13 days and 19 days, respectively. The wasps suppressed these populations to 84 larvae and 68 pupae over a 90 day interval. However, the adult and eggs populations were not suppressed as the population had reached the maximum limit of 25 in 6 days, also because the wasps introduced here can only attack the 2nd or 3rd instar larvae stages. Any larvae that escapes parasitism will transform into pupae and then into adults that continue reproduction.

Analysis of system

From our model, we are able to identify that *Scoliidae* and *Tachinidae* wasps can only attack the larvae stage of scarab beetles, therefore any larvae that escape attack will definitely undergo transformation to the adult stage, there by continuously increasing the number of the adult beetles, whose population will only be reduced by natural mortality. The adult will continue reproducing and will only die at the due time because there is no control measure to terminate the adult beetles. As long as the adult female beetles live, daily reproduction is certain. The model demonstrates control of the beetles' larvae and pupae population to an acceptable level, given time. The use of pesticides has the tendency to cause pest out breaks because, insecticides do not only kill the pest but will completely eliminate the naturally beneficial parasitoid wasps.

Recommendation

We therefore recommend the deployment of *scoliidae* and *tachinidae* wasps in combination with the introduction of a biocontrol agent either a virus or fungi, which can attack the adult beetles to force its population down. Care should be taken when choosing a virus or fungi, in order not to create an ecological disaster by eliminating both the adult beetles with a concomitant effect on the naturally beneficial insects.

CONCLUSION

To successfully reduce scarab beetle population to an economically acceptable threshold, chemical pesticides should never be used in beetle infested habitats. The introduction of naturally beneficial insects in cocoyam or taro habitats should be encouraged as soon as a scarab beetle is detected or the larvae is sited. Best practice for scarab beetle management has been successfully designed and analysed. In future we shall try to model a system of wasps in combination with a bio-control agent to prove the effectiveness of natural control methods.

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